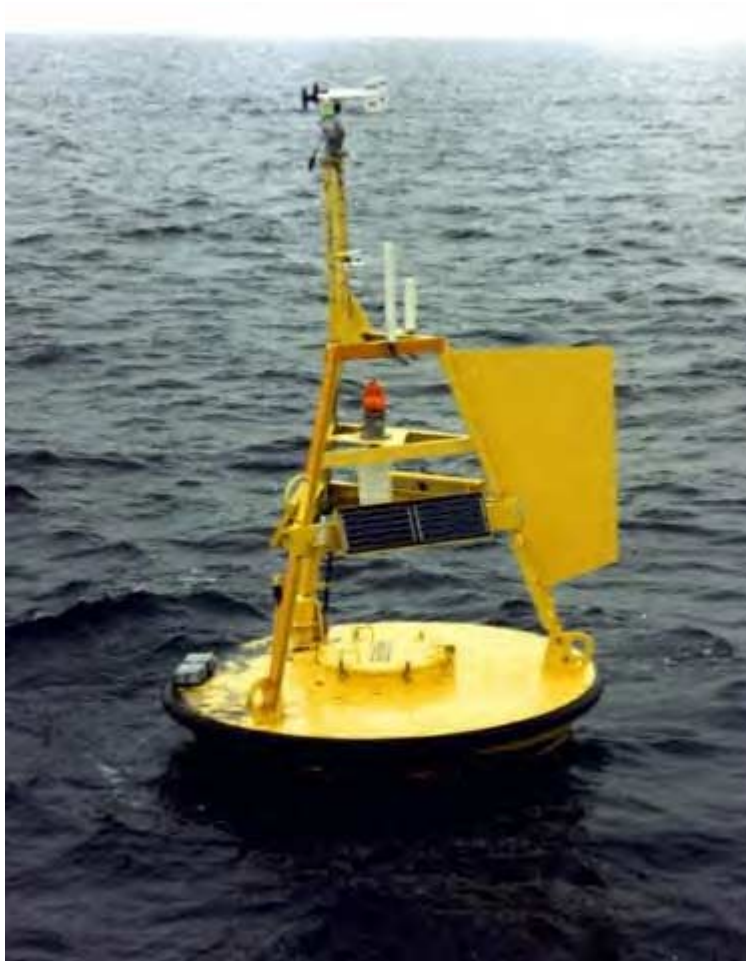


MONTEREY BAY BUOY 46042 WAVE STUDY



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INTRODUCTION

The purpose of this report was to study wave swell events in the Monterey Bay. Meteorological and oceanographic data was obtained from the National Data Buoy Center (NDBC) Monterey Buoy, Station 46042 for the month of December to study wave swells. This buoy is a three-meter discus buoy with a DACT payload and is located at $36^{\circ}45'11''\text{N}$ $122^{\circ}25'21''\text{W}$ (Figure 1). It is a deep-water buoy, in 1,920 meters of water. This buoy is capable of measuring air, sea surface, and dewpoint temperatures, sea level pressure, wind speed and direction, gust speeds, significant wave height, average and dominant wave periods, and mean wave direction. This study only considered the wind and wave measurements.

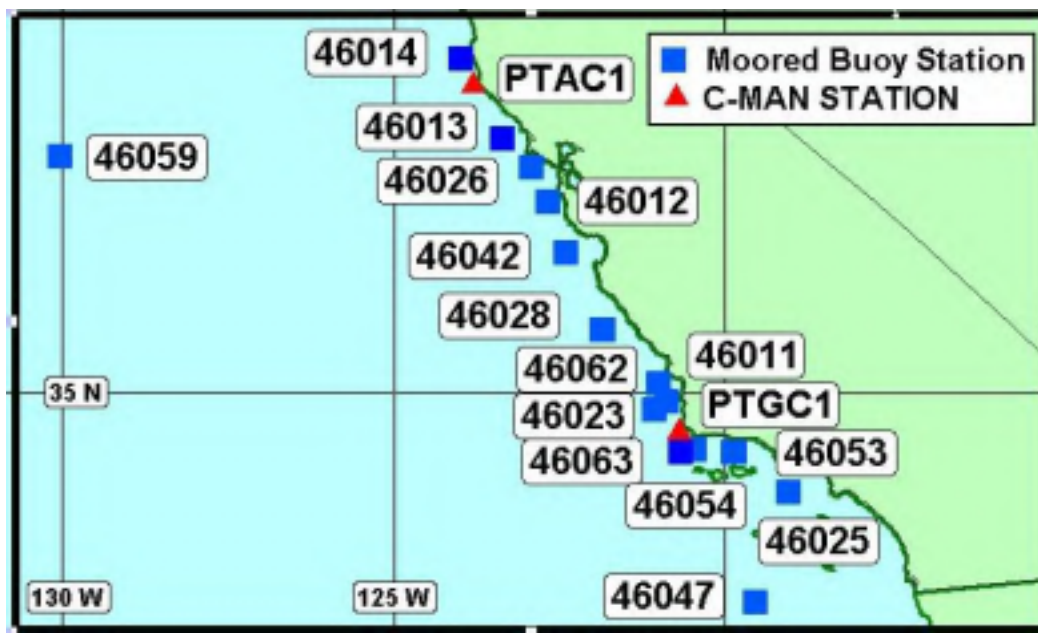


Figure 1. Location of Monterey Bay Buoy.

The military, scientists, and commercial companies are all concerned with developing accurate models for predicting sea state conditions, not only to save lives, but also to save money and time. Before an accurate prediction can be made, it is important and necessary to study the sea and its wave dynamics. Seas develop waves of varying directions, heights, and energies. A statistical approach to studying waves involves spectral analysis. The wave energy spectrum in Figure 2 shows a general range of periods observed in ocean waves. Wind speed, duration, and fetch all affect wave characteristics and sea state. The wind generally only develops the short period waves. The longer period swells generally develop from distant storms rather than from local wind conditions.

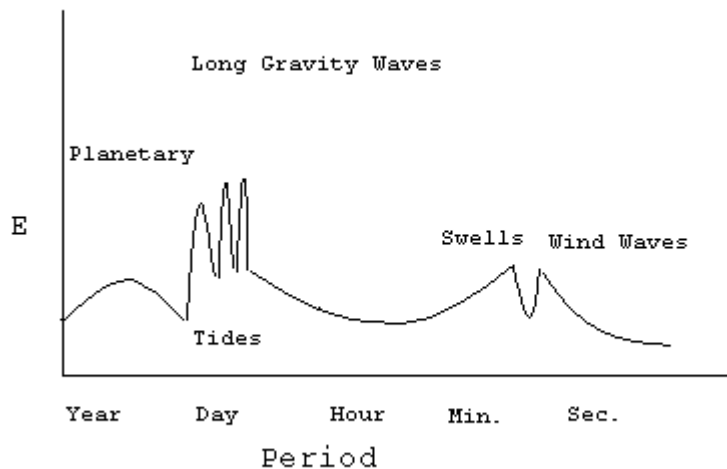


Figure 2. A relative energy vs. period plot for waves observed in the ocean.

DATA COLLECTION

The data used in this study was collected by the buoy's instruments every hour. Wind speed (m/s) and direction (degrees in the direction the wind is coming from) measurements were averaged over an eight-minute observation period. A unit-vector average was used to calculate the direction, where a unit vector and the wind u and v components for each observation were averaged and used to compute the average direction. Significant wave height (meters) was calculated as the average of the highest one-third wave heights during a twenty-minute sampling period. The average wave period (seconds) was calculated during the same twenty-minute sampling period. The dominant wave period (seconds) is the period of maximum wave energy and the mean wave direction (degrees) corresponds to the energy in this period.

The wave measurements that are reported by NDBC are not directly measured by the sensors on the buoy. The buoy sensors measure heave acceleration or vertical displacement of the buoy during a twenty-minute sampling time. The buoy processor applies a Fast Fourier Transform (FFT) on the data to transform the temporal data into frequency domain. Then, response amplitude operator (RAO) processing is carried out to account for hull and electronic noise. The

DACT Payload sensors' reporting, sampling, and accuracy are listed in Table 1.

Parameter	Range	Freq.	Average Period	Resolution	Accuracy
Wind Direction	0-360°	1.0 Hz	8 minutes	1.0°	±10.0°
Wind Speed	0-62 m/s	1.0 Hz	8 minutes	0.1 m/s	±1.0 m/s
Wind Gust	0-82 m/s	1.0 Hz	5 seconds	0.1 m/s	±1.0 m/s
Air Temperature	-40-50 °C	1.0 Hz	8 minutes	0.1 °C	±1.0 °C
Pressure	800-1100 hPa	1.0 Hz	8 minutes	0.1 hPa	±1.0 hPa
Water Temperature	-6-40 °C	1.0 Hz	8 minutes	0.1 °C	±1.0 °C
Wave Height	0-35 m	2.56 Hz	20 minutes	0.1 m	±0.2 m
Wave Period	0-30 sec	2.56 Hz	20 minutes	1.0 sec	±1.0 sec
Wave Spectra	0-999 m ² /Hz	2.56 Hz	20 minutes	0.01 Hz	±0.01 Hz
Wave Direction	0-360°	2.56 Hz	20 minutes	0.1°	NA

Table 1. NDBC buoy 46042 DACT payload sensor reporting, sampling, and accuracy.

The buoy reports spectral wave density in m²/Hz for each frequency bin (0.03-0.40 Hz, with a bin width of 0.01 Hz). The directional wave spectrum reports consist of mean direction (*ALPHA1*), principle wave direction (*ALPHA2*), *R1*, and *R2* (parameters that describe the directional spreading). The buoy uses a Hippy heave-pitch-roll sensor to determine sea surface height and tilt in the x-y directions.

DISCUSSION

The data was analyzed using Matlab version 5.2. Missing data was filtered out and a composite contour plot of wave energy (Figure 5) was made to initially identify swell events. The energy spectrum was used because it is related to the energy of the waves. The directionality of wave can be described by mean direction θ_{mean} , and directional spread σ_θ , graphically defined in Figure 3.

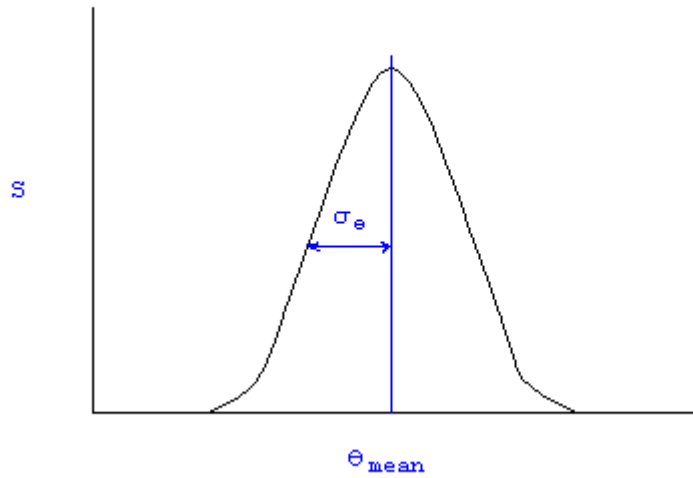


Figure 3. $S(\theta)$ is the normalized directional distribution of energy $S(\theta; \omega)$ at frequency ω .

The buoy reported $R1$, a parameter that described directional spreading. To calculate σ_θ , the following relationship was used:

$$\sigma_\theta = [2 \times (1 - R1)]^{1/2}, \text{ where } R1 = [a_1^2 + b_1^2]^{1/2}.$$

As expected, the highest energies were found in the lower frequencies. The largest energies were found on 22 December to 23 December. This is also where the highest

significant wave heights were found. Three records were then analyzed separately, 22 December 00Z, 12Z, and 18Z (Figures 6-8). The peak of the swell event occurred at 18Z. Figure 6 shows the wave energy and directionality just prior to the swell event, at 00Z. The energy peaked at two different periods, 14 seconds and 10 seconds, both around $0.6 \text{ m}^2/\text{Hz}$. Figure 7 shows the wave energy and directionality at the beginning of the swell event, when the peak energy increased to $15 \text{ m}^2/\text{Hz}$ for a 14 second period. Figure 8 shows the wave energy and directionality at the peak of the swell event, with an energy peak of $100 \text{ m}^2/\text{Hz}$ and a 16 second swell. The mean direction indicates the source of the swells to be from the northwestern Pacific Ocean, ranging from 272° to 304° true over the course of the swell event. The spectrum narrowed as the energy increased. The directional spread was between 12° and 14° for the swell event. The swell periods ranged from 10-17 seconds during the swell event, compared with local wind-generated wave periods of 1 to 4 seconds.

Figure 4 shows a satellite picture from 23 December at 18Z. The front just north of Monterey Bay is the probable system that generated the swell event on 22 December. The

movement of the cloud structures is in the same direction of the swells.

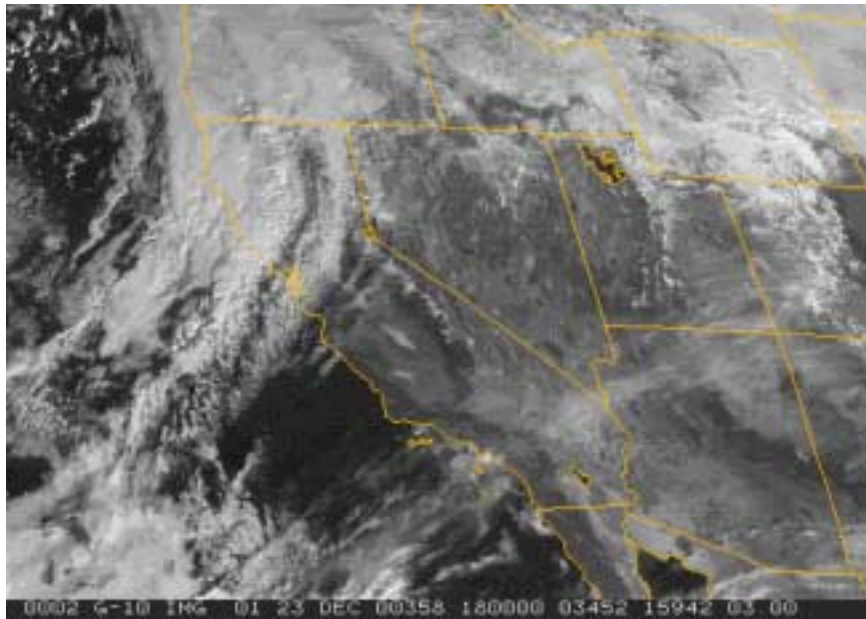


Figure 4. Visible image from 23 December 2000.

Winds direction and speed were also studied. A time series plot of wind direction (Figure 9) shows the local winds measured by the buoy. Wind speeds range from 1 to 12 m/s. Figure 9 also shows the wind direction for December, ranging from northeast to northwest. Diurnal events can also be seen with land breezes from the east.

The third plot on Figure 9 is of the buoy measured significant wave height. A local wind estimate of significant wave height (red) was done to see if local winds were strong enough to produce the waves. The relationship between the winds and significant wave height can be found by integrating the Pierson-Moskowitz spectrum

$$E(f) = \alpha g^2 / ((2\pi)^4 f^5) \exp[-\beta (2\pi f U / g)^{-4}]$$

$$\text{variance} = \int_0^\infty E(f) df = \alpha U^4 / (4\beta g^2)$$

$$H_s = 2(\alpha/\beta)^{1/2} (U^2/g)$$

where $\alpha = 8.10 \times 10^{-3}$ and $\beta = 0.74$ (Hasselmann *et al.*, 1973). As Figure 9 shows, the local winds were not strong enough, or the fetch and duration of the local winds were not long enough, to produce the waves measured by the buoy. Some exceptions can be seen on a few isolated days for a short period of time, but these are not significant or for more than two measurement records. As expected, the local winds would not be strong enough to generate the higher significant wave heights measured during the swell events in December.

Figure 10 shows a plot of the dominant wave period measured by the buoy and a peak period estimated from the local winds using the relationship from Hasselmann *et al.* (1973)

$$f_p = g / (2\pi U).$$

As expected, the estimated peak wave period would be less than the measured wave period.

The second plot on Figure 10 shows the mean wave direction, which ranges from 253° to 321° throughout December. This indicates that the source of the swells is

from the western to northwestern Pacific Ocean, implying an unlimited fetch region for large swells to grow.

Since the heave-pitch-roll buoys, like the Monterey Buoy, have become widely used, studies have been conducted to estimate their performance. The NDBC three-meter discus buoys are the principle source of offshore directional wave measurements in the United States (O'Reilly *et al.*, 1996). Generally, a buoy records 1000 to 4000 data points for a 1 to 2 Hz time series. This ensures a long enough record to prevent aliasing or spectral leakage. These buoys have simple systems that provide the first four Fourier coefficients, enough for mean direction and directional spread analysis (Krogstad, 1991). It should be noted that even though the buoy provides both wave and meteorological data, the type of stable platform required for the most accurate wind measurements conflicts with the ideal wave following platform (O'Reilly *et al.*, 1996).

CONCLUSION

The data used for this study was easily obtained from the NDBC website. Matlab was very helpful in processing the data. For a more complete study of wind-wave interactions, more accurate wind data must be obtained. Rawinsonde launches at the buoy location would be ideal, but not likely to occur because of cost and logistical

problems. The Fort Ord profiler could also be used for the wind data, but it is possible that the shape of the bay area could create some error between the profiler measured winds and the actual winds at the buoy offshore. Satellite data could be used, however, if a study were conducted from previous data instead of real-time data, archived images are not easily located. Wind data derived from models could also be used, but the analysis would have to consider any model biases. December only had one storm swell event, more study should be done during months of increased storm activity, such as October.

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